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(71) Applicant(s)
Courtaulds Aerospace Limited

(Incorporated in the United Kingdom)

P O Box 111, 72 Lockhurst Lane, COVENTRY, CV6 5RS, United Kingdom

(72) Inventor(s)
Andrew Peter Slater

(74) Agent and/or Address for Service
J Y & G W Johnson
Furnival House, 14-18 High Holborn, LONDON, WC1V 6DE, United Kingdom

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U1S S1828

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GB 2144973 A EP 0169432 A EP 0024713 A2
US 4868040 A US 4732803 A US 4613535 A

(58) continued overleaf

(54) **Composite ballistic armour**

(57) A rigid ballistic armour composite (10) comprises in sequential order a strike face layer (11), a core layer (13) and a backing layer (12) each of which comprises a polymer matrix containing a fibre reinforcement, the core layer being laminated between the strike face layer and the backing layer, the polymer matrix of the strike face layer and the backing layer each comprising a structural polymer preferably epoxy resin, and the polymer matrix of the core layer comprising a ballistic polymer different from the structural polymer of the strike face layer and backing layer. The core polymer is selected from phenolic, vinylester and polyester resins, polyetheretherketones, polyethersulphones, polysulphones, polyetherimides, polyarylketones, polyethylene, polyproplylene, polycarbonates, polystyrenes, polyurethane, and rubbers. Reinforcements may include various glass fibres and organic fibres including ultra-high molecular weight polyethylene.

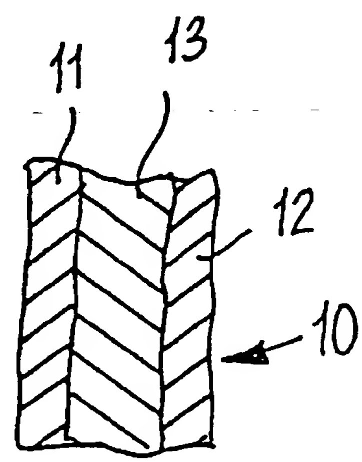


FIG. 1

GB 2 277 141

(58) Field of Search
UK CL (Edition M ) B5N , F3C CP2
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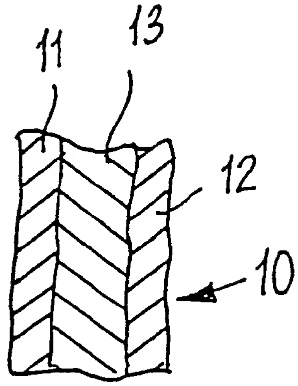


FIG. 1

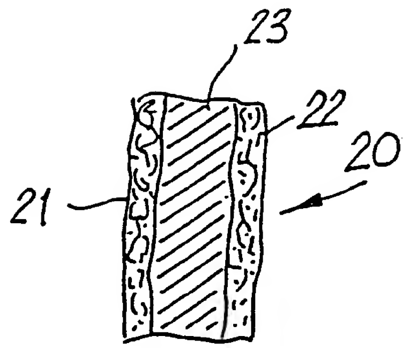


FIG. 2

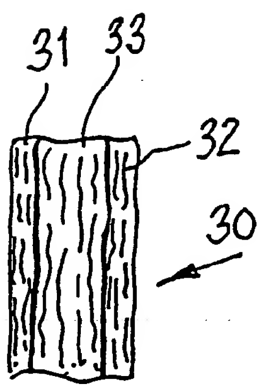


FIG. 3

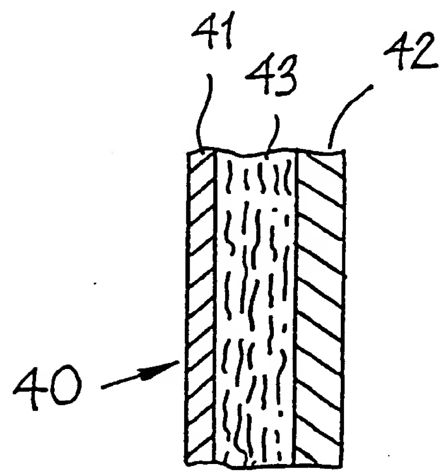


FIG. 4

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## Ballistic Armour Sandwiched Composites

This invention relates to a ballistic armour composite, that is to say a rigid composite which comprises reinforcing fibre or fabric embedded in a polymer matrix.

Polymer composites are gaining importance in ballistic protection for military and civilian personnel, due mainly to the high strength, stiffness, and elongation provided by man-made fibres. Such composites offer many advantages over metal armour, including high durability, light weight and low maintenance costs.

Various composites have been proposed in the past for use in ballistic protection. A commonly used composite comprises a laminated structure consisting of woven or knitted glass fibre structures embedded in various matrices such as for example epoxy resin, polyester resin or phenolic resin. In the main, prior known composites have comprised a single type of fibre as the reinforcement embedded in one or more polymer matrices.

A commonly used reinforcement for ballistic resistant composites are fabric layers made from aromatic polyamide fibres (often also called aramid or polyaramid fibres) of which "Kevlar" (a trademark of Du Pont), "Twaron" (a trademark of Enka) and "Technora" (a trademark of Teijin) are the best known. Aromatic polyamide fibres and fabrics offer significantly better ballistic performance than fibre glass reinforced composites but compared with fibre glass reinforced composites are considerably more expensive.

Another suggested reinforcement for ballistic resistant composites are fabric layers made from ultra-high molecular weight (i.e. molecular weights greater than 1,000,000) polyethylene fibres of the type known as "Dyneema" (a trademark of DSM) and that known as "Spectra" (a trademark of Allied-Signal Corporation). Dyneema and Spectra fibres also

have a better ballistic performance than glass fibre reinforced composites but compared with glass fibre are more expensive.

The ballistic performance of various composites in terms of their resistance to penetration by projectiles may be tested and compared in many different ways. One convenient way, for example, is to fire a known sized projectile at samples of the composite and to record the velocity at which, theoretically, 50% of the projectiles penetrate the composite and the other 50% are stopped by the composite. This velocity is often referred to as the $V_{50}$ velocity.

If one carries out ballistic performance tests on a lightweight composite comprising glass fibres embedded in, for example, a phenolic resin, one arrives at a much lower $V_{50}$ velocity than one would achieve with a composite made using aramid fibres or ultra-high molecular weight polyethylene fibres, using the same test.

The design of ballistic armour is a compromise between the weight, cost, ballistic performance and thickness of the composite, in relation to what the perceived ballistic threat is likely to be. In other words, if the threat is likely to be from small arms munitions, then one type of composite may be more suited than another, but if the perceived threat is from, for example, fragments of an artillery shell, then different composites may be more suited than those used for the small arms threat.

There are many instances, for example in the design of armoured vehicles, where there is a need for ballistic armour panels which also have structural strength. In the main, the approach to the design of armour for such applications has been to construct the vehicle of components which transmit or carry the structural loads and to provide separate or additional panels that provide the ballistic protection. With the tendency to move towards designs of vehicles in which the

ballistic protection is in the form of a monocoque body, there is a need for ballistic armour composites which possess structural strength and thus can serve as structural load-carrying members.

One aim of the present invention is to provide a hybrid composite ballistic armour which has a good ballistic performance and is capable of carrying structural loads.

US-A-3,486,966 (Allen et al.) describes a light weight ballistic panel which consists of alternating laminations of glass fibre cloth and nylon cloth, the whole being bonded together by a polyurethane plastic. Other plastics are said to lack the resiliency and strength of polyurethane, so that laminated panels made with such other plastics shatter and fail to resist penetration by bullets.

US-A-3,832,265 (Denommee) describes a ballistic armour laminate which consists of a plurality of plies of woven nylon ballistic fabric and woven roving fibreglass fabric, the whole being bonded together with a polyester resin. The laminate is constructed so that the plies of one fabric constituting the interior portion of the laminate are surrounded on opposite sides thereof by one or more plies of the other fabric, with the number of plies of the latter fabric being equal in number on each side thereof.

According to the present invention there is provided a rigid ballistic armour composite which includes in sequential order a strike face layer, a core layer and a backing layer each consisting of a fibre-reinforced polymer matrix, the core layer being laminated to the strike face layer and to the backing layer, characterised in that both the polymer matrix of the strike face layer and the polymer matrix of the backing layer are structural polymers and that the polymer matrix of the core layer is a ballistic polymer different from the polymer matrix of the strike face layer and from the polymer matrix of the backing layer. As used herein, the strike face

layer is considered to consist of a strike face fibre in a strike face polymer matrix; the core layer to consist of a core fibre in a core polymer matrix; and the backing layer of a backing fibre in a backing polymer matrix.

The strike face fibre, the core fibre and the backing fibre may each be of calcium aluminoborosilicate glass fibres, for example, E-glass fibres with an alkali content of less than 2% by weight, or of magnesium aluminosilicate glass fibres such as those known as S-glass, S2-glass or R-glass fibres, or of aramid fibres such as those known as Kevlar* or Twaron* or Technora*, or of ultra-high molecular weight polyethylene fibres such as those known as Dyneema* or Spectra* (* = Trade Marks).

The structural polymer is a hard tough material which is preferably an epoxy resin, although some types of polyester resin may also be suitable. The structural polymers in the strike face layer and in the backing layer may be the same or different. The ballistic polymer is such that it produces a more energy-absorbing fibre reinforced composite in comparison with the structural polymer.

The core polymer is preferably selected from the group of materials consisting of the following:- phenolic resins, vinylester resins, polyester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrenes and polyacrylates. Styrene-butadiene-styrene (SBS) rubbers and polyurethane (PU) rubbers may also be used when ultra-high molecular weight polyethylene fibre is used as the core fibre. The core polymer is an energy-absorbing ballistic polymer, in contrast to the hard structural (e.g. epoxy resin) strike face polymer and backing polymer.

The fibrous reinforcement in each of the layers may comprise a plurality of layers or plies of fibres arranged

unidirectionally or multidirectionally. However the preferred form of fibrous reinforcement, preferably in all the layers, is that of a fabric which may be a woven fabric, a non-woven fabric, or a knitted fabric.

The areal weight of a single ply of glass fibre fabric and the polymer resin associated therewith is preferably in the range 500 to 1500 g/m². The areal weight of a single ply of aromatic polyamide fibre fabric and the polymer resin associated therewith is preferably in the range 100 to 600 g/m². The areal weight of a single ply of other types of fabric and the polymer resin associated therewith is preferably in the range 100 to 400 g/m².

The areal weight of a composite according to the invention may be in the range 1 to 100 kg/m². Composites with areal weight in the range 4 to 20 kg/m² may be preferred for use in personal armour. Composites with areal weight in the range 20 to 80 kg/m² may be preferred for use in vehicle armour. Such composites may be used in the fabrication of vehicle bodies or as secondary armour on a vehicle body. Composites according to the invention provide good protection against fragments, bullets and restrict the effects of shaped charge weapons.

The core layer may amount to about 30 to about 70 per cent by weight of the composite. The strike face layer and backing layer are generally of similar weights.

A composite according to the invention may additionally comprise a flame retardant layer on one or both sides, for example one or two plies of glass fibre such as E-glass or S-glass impregnated with a resin such as a phenolic resin. Such a flame retardant layer may be about 1 mm thick, and have areal weight around 2000 g/m². Such a flame retardant layer serves to inhibit an underlying epoxy resin layer from catching fire or emitting smoke.

A composite according to the invention may additionally comprise a ceramic layer upon the strike face layer. Such a ceramic layer provides good ballistic protection and additionally serves as a flame retardant layer upon the strike face.

The present invention will now be more fully described, by way of examples, with reference to the accompanying drawing in which:-

Figures 1 to 4 show schematically the cross section through four composites constructed in accordance with the present invention.

The composite 10 shown in Figure 1 comprises three layered rigid portions 11, 12 and 13. Portion 11 defines the strike face of the armour (the strike face being the surface which would face towards projectiles directed at the composite). Portion 12 defines a backing portion and together with the portion 11 provides the structural strength of the composite. Portion 13 constitutes a central core and provides the main part of the ballistic resistance of the composite.

Portions 11 and 12 each comprise a stack of glass fibre fabrics made from E-glass which are preimpregnated with an epoxy resin. A suitable epoxy resin is that made by Courtaulds Aerospace Limited under their reference EP29.

A typical E-glass composition comprises (by weight) 52 to 56% silica, 12 to 16% alumina, 16 to 25% calcium oxide, 0 to 5% magnesia, 5 to 10% boron oxide, 0 to 2% sodium oxide, and 0 to 1-5% total of minor oxides, and has an alkali content of less than 2%. Such E-glasses have a Youngs Modulus of Elasticity of approximately 70 to 85 GPa at 20°C (68°F) and an elongation of the order of 3 to 5%. The preferred E-glass is that manufactured by PPG Industries under yarn reference ECR 1472 (2300 Tex) with filament diameter K (12 to 13 micron). This yarn is precoated by the manufacturer with an

epoxy compatible size.

The preferred form of the reinforcement is that of a woven fabric comprising a plain weave (manufactured by Courtaulds Aerospace Limited under the reference code YO224). This fabric comprises 1.97 ends/cm by 1.57 picks/cm with a nominal areal weight of 830 g/m². No additional fibre finish was applied during weaving. E-glass fibres of the order of 2 to 32 micron diameter can be woven to make suitable fabrics having 1 to 15 picks/cm and 1 to 15 ends/cm. The E-glass fibre is preferably precoated with a size compatible with the matrix material. Suitable sizes comprise silanes or a thermoplastic or starch oil to achieve a suitable adhesive bonding between the fibres and the matrix.

E-glass fabrics were impregnated by Courtaulds Aerospace Limited with 27 ± 2% by weight epoxy resin (their reference EP29) to give prepregs having a nominal areal weight of 1137 g/m². (Resin content is expressed herein as a weight percentage of the prepreg.)

Portion 13 comprises a stack of S2-glass fibre fabrics which are preimpregnated with phenolic resin. A suitable phenolic resin is that manufactured by Borden (UK) Limited under reference number SC1008P, or that made by Courtaulds Aerospace Limited under their reference PH16 (this is a polyvinylbutyral modified phenolic resin). 18 ± 2% by weight phenolic resin is impregnated into each fabric layer to give a prepreg of nominal areal weight of 1012 g/m².

The S2-glass fibres have a nominal composition (by weight) of 64% silica, 25% alumina, 10% magnesium, 0.3% sodium oxide and 0.7% total of other minor oxides. Such S2-glasses have a Youngs Modulus of Elasticity of approximately 80 to 95 GPa at 20°C (68°F) and an elongation of 3 to 7%. The preferred S2-glass is an S2-glass manufactured by Owens-Corning Fiberglas Inc. under yarn reference 463 AA-250 (nominal 244 yds/lb (1984 tex)). This yarn has filament size

G (9 micron) and is coated by the manufacturer with an epoxy compatible size which has the manufacturer's code reference 463. The yarn was woven by Courtaulds Aerospace Limited to give a fabric (Ref.YO554) comprising 1.96 ends/cm by 1.97 picks/cm plain weave. The fabric had a nominal areal weight of 830 $g/m^2$. No additional fibre finish was applied during weaving.

Prepreg fabrics defining portions 11, 12, 13 were laid up in a mould and compression moulded under heat and pressure to out-gas and consolidate the composite to make a rigid unitary body.

The epoxy-resin-impregnated portions 11 and 12 provide the main structural strength of the composite and together with the phenolic-resin-impregnated core portion 13 provide ballistic resistance.

In the above example, E-glass has been used in the portions 11 and 12. It is to be understood that reinforcement made of other types of fibres, for example, S-glass, S2-glass, R-glass or aromatic polyamide may be used in the portions 11 and 12 and that a different reinforcement can be used in each portion.

The preferred reinforcement in the core portion 13 is of S2-glass. However, if desired, the reinforcement in core portion 13 may be selected from the following materials:- S2-glass, E-glass, aromatic polyamide, ultra-high molecular weight polyethylene, aliphatic polyamide or aromatic polyester.

The preferred form of the reinforcement in portions 11, 12 and 13 is a fabric which may be a knitted, woven or non-woven fabric. Furthermore, each reinforcement layer could be in the form of unidirectional or multi-directional fibres. Indeed each reinforcement could comprise a plurality of layers of fabric, unidirectional fibres or multi-directional fibres.

The unidirectional fibres in one layer may lie at an angle to those in adjacent layers. The lay up of such reinforcement is well known in the art of making composite materials.

In the above example the epoxy resin polymer matrix and the fibrous reinforcement was the same in each of the strike face portion 11 and the backing portion 12.

The preferred matrix polymer material for the core portion 13 is a phenolic resin, but an acceptable ballistic performance can be achieved with other matrix materials. The matrix of the core portion 13 may be one or more of the following group of polymer material materials, namely: phenolic resins, polyester resins, vinylester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrene and polyacrylates. When polyethylene fibre reinforcement is used, alternative matrix materials include styrene-butadient-styrene (SBS) rubbers and polyurethane (PU) rubbers.

Referring to Figure 2 a composite 20 comprises three portions 21, 22 and 23. Portion 21 defines the strike face of the armour. Portion 22 defines a backing portion and together with portion 21 provides the main structural strength of the composite. Portion 23 constitutes a central core portion and provides the main part of the ballistic resistance of the composite.

Portions 21 and 22 each comprise a stack of S2-glass fibres impregnated with 27 ± 2% by weight epoxy resin (reference EP29) to give a prepreg with an areal weight of 1012 $g/m^2$.

The core portion 23 comprises a stack of aromatic polyamide fabrics (such as for example Kevlar, Twaron or Technora) impregnated with 18% + 2% by weight of phenolic resin. The same phenolic resins as used in portion 13 of

Figure 1 were used for the portion 23 of Figure 2.

Here again the portions 21, 22 and 23 were laid up in a mould and compression moulded under heat and pressure to form the rigid composite 20.

Referring to Figure 3 there is shown a third composite 30 in which the outer portions 31 and 32 each comprise a stack of S2-glass fabrics made from the same yarn as shown in Figure 1 and impregnated with 27 ± 2% by weight of the same epoxy resin as used in Figures 1 and 2.

The core portion 33 of the composite 30 of Figure 3 comprises fabrics woven from ultra-high molecular weight polyethylene (which may be Dyneema or Spectra fibres) impregnated with a low density polyethylene (20% by weight) as matrix polymer.

The rigid composite 30 is formed by compression moulding the laminated portions 31, 32 and 33 separately and subsequently bonding them together using an adhesive such as a polysulphide adhesive, for example Bostik 2114 (Bostik is a trademark of Bostik Limited).

In another variation of the composite shown in Figure 3 the ultra high molecular weight polyethylene fibre in core portion 33 is embedded in a vinylester resin matrix instead of low density polyethylene. In this case either the portions 31, 32 and 33 could be made separately and bonded together using an adhesive or they could be co-moulded.

In a further variation, plies of the ultra-high molecular weight polyethylene fibre fabric are interleaved with low density polyethylene film, and the resulting stacked assembly subjected to heat and pressure to form the core laminate. In this case, portions 31, 32 and 33 are preferably made separately and subsequently bonded using a suitable adhesive.

Referring to Figure 4 there is shown a further composite 40 constructed in accordance with the present invention. The composite of Figure 4 comprises a portion 41 defining a strike face and a backing portion 42 each of which comprises two plies of S2-glass fabric embedded in epoxy resin EP29 (27% by weight resin content). The core portion 43 comprises four plies of S2-glass fabric in phenolic resin SC1008 (18% by weight resin content). The areal weight of the composite 40 was in the range of 7.5 to 7.9 kg/m².

Table I shows the ballistic and mechanical performance data for two reference composites A and B compared with the composite of Figure 4. The reference composite A comprised eight plies of S2-glass fabric (reference YO554) in phenolic resin SC1008 (18% resin content) and composite B comprised eight plies of S2-glass fabric (reference YO554) in epoxy resin EP29 (27% resin content). The areal weights of the composites A and B were each in the range of 7.5 to 7.9 kg/m². The ballistic tests were carried out in accordance with UK/SC/4697 using 1.1 g fragment simulators. The mechanical tests were carried out in accordance with BS 2782, part III method 335A and method 320E.

**Table 1**

| | $V_{50}$ m/s | Flexural Strength MPa | Tensile Strength MPa |
|---|---|---|---|
| Composite A | 410 | 210 | 590 |
| Composite B | 384 | 730 | 710 |
| Fig 4 Composite | 411 | 650 | 680 |

From Table 1 it will be seen that the composite of Figure 4 has a good ballistic performance ($V_{50}$) (as good as the composite A and better than B), and good mechanical strength (better than composite A and nearly as good as composite B). Thus the composite in accordance with the present invention

has an optimised balance of ballistic performance and mechanical strength compared with composites A and B.

## CLAIMS

1. A rigid ballistic armour composite which includes in sequential order a strike face layer, a core layer and a backing layer each consisting of a fibre-reinforced polymer matrix, the core layer being laminated to the strike face layer and to the backing layer, wherein both the polymer matrix of the strike face layer and the polymer matrix of the backing layer are structural polymers and that the polymer matrix of the core layer is a ballistic polymer different from the polymer matrix of the strike face layer and from the polymer matrix of the backing layer.

2. A composite according to claim 1, wherein the structural polymer in the strike face layer or the backing layer or both is an epoxy resin.

3. A composite according to claim 1 or claim 2, wherein the ballistic polymer is selected from the group consisting of phenolic resins, polyester resins, vinylester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrene and polyacrylates.

4. A composite according to claim 1 or claim 2, wherein the reinforcing fibre in the core layer comprises ultra-high molecular weight polyethylene fibres and the ballistic polymer is a styrene-butadiene-styrene (SBS) rubber or a polyurethane (PU) rubber.

5. A composite according to any one preceding claim, wherein the reinforcing fibre in each of the strike face layer, the core layer and the backing layer is selected from the group consisting of glass fibres, aliphatic polyamide fibres, aromatic polyester fibres, aromatic polyamide fibres and ultra-high molecular weight polyethylene fibres.

6. A composite according to claim 5, wherein the reinforcing fibre in the strike face layer and in the backing layer is the same material.

7. A composite according to claim 5, wherein the reinforcing fibre in the strike face layer, the core layer and the backing layer is the same material.

8. A composite according to claim 5 or claim 6, wherein the reinforcing fibre in the strike face layer and in the backing layer comprises calcium aluminoborosilicate glass fibres.

9. A composite according to claim 8, wherein the calcium aluminoborosilicate glass fibres are E-glass fibres.

10. A composite according to claim 5, 6 or 7, wherein the reinforcing fibre in the core layer comprises magnesium aluminosilicate glass fibres.

11. A composite according to claim 10, wherein the magnesium aluminosilicate glass fibres are S-glass, S2-glass or R-glass fibres.

12. A composite according to either of claim 5 or claim 6, wherein the reinforcing fibre in both the strike face layer and the backing layer comprises calcium aluminoborosilicate glass fibres and the reinforcing fibre in the core layer comprises magnesium aluminosilicate glass fibres.

13. A composite according to either of claim 5 or claim 6, wherein the reinforcing fibre in both the strike face layer and the backing layer comprises magnesium aluminosilicate glass fibres and the reinforcing fibre in the core layer comprises aromatic polyamide fibres.

14. A composite according to either of claim 5 or claim 6, wherein the reinforcing fibre in both the strike face layer

and the backing layer comprises magnesium aluminosilicate glass fibres and the reinforcing fibre in the core layer comprises ultra-high molecular weight polyethylene fibres.

15. A composite according to claim 5, 6 or 7, wherein the reinforcing fibre in each of the strike face layer, the core layer and the backing layer comprises magnesium aluminosilicate glass fibres.

16. A composite according to any one preceding claim, wherein the strike face layer and/or the core layer and/or the backing layer comprises a plurality of plies of fibres.

17. A composite according to claim 16, wherein the plies of fibres are woven, non-woven or knitted fabrics.

18. A composite according to any one preceding claim, wherein its areal weight is in the range 1 to 100 kg/m$^2$.

19. A composite according to claim 18, wherein its areal weight is in the range 20 to 80 kg/m$^2$.

20. A composite according to any one preceding claim, wherein it additionally comprises a flame-retardant layer upon the strike face and/or the backing face.

21. A composite according to any one preceding claim, wherein it is additionally provided with a ceramic layer upon the strike face.

22. A rigid ballistic armour composite substantially as herein described with reference to the accompanying drawing.

23. A method for the manufacture of a rigid ballistic armour composite substantially as herein described with reference to the accompanying drawing.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Application number
GB 9406611.5

**Relevant Technical Fields**

(i) UK Cl (Ed.M) F3C CP2 B5N

(ii) Int Cl (Ed.5) F41H

Search Examiner
PAUL GAVIN

Date of completion of Search
20 JUNE 1994

Databases (see below)
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(ii) ONLINE WPI

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&: Member of the same patent family; corresponding document.

| Category | Identity of document and relevant passages | | Relevant to claim(s) |
|---|---|---|---|
| X | GB 2144973 A | (FIGGIE) whole document | 1 at least |
| X | EP 0169432 | (VAL MEHLER) whole document | 1 at least |
| X | EP 0024713 A2 | (THIELE) whole document | 1 at least |
| X | US 4868040 | (CANADIAN P&D) whole document | 1 at least |
| X | US 4732803 | (SMITH) whole document | 1 at least |
| X | US 4613535 | (HARPELL) whole document | 1 at least |

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